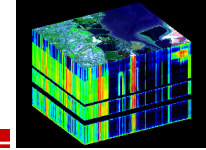


Imaging Spectroscopy Technology Investments

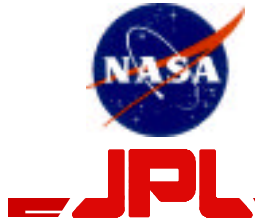


Imaging Spectroscopy Technology Investments

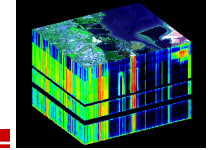
*Paving the Way for Low-Cost, High-Quality
Sensor Systems for
NASA Code Y Science Programs*

Robert O. Green
David A. Thomas
Jet Propulsion Laboratory

May 1999



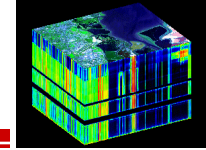
Topics



- **Objective and Overview of Briefing**
- **Code Y Science Objectives**
- **Measurement Requirements**
- **Today's State-of-Practice**
- **Required Technologies - Some Examples**
- **Summary**

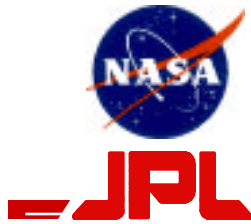


Objective and Overview of Briefing



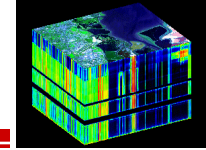
Objective

- **Present rationale for technology investment**
- **Preview a few key candidate technologies**



Imaging Spectroscopy Technology Investments

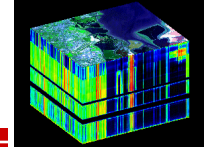
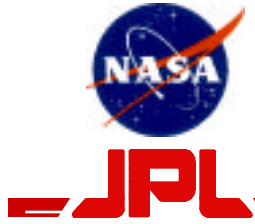
Objective and Overview of Briefing



Overview

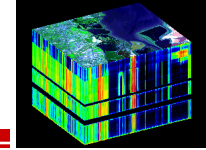
- **NASA Imaging Spectroscopy has reached a unique juncture because sufficient information now exists for:**
 - Code Y to quantify its Science Requirements
 - JPL to quantify corresponding Measurement and Engineering Requirements
- **Assessment of today's State-of-Practice (SoP) Imaging Spectrometers reveals that:**
 - Those with nominal performance are too large to fly in space (e.g., AVIRIS)
 - Those being built to fly in space do not meet the performance requirements
 - Nominal performance with today's SoP would be very large and expensive

We will show that a modest investment in advanced technology can bridge the gap between high performance and low cost

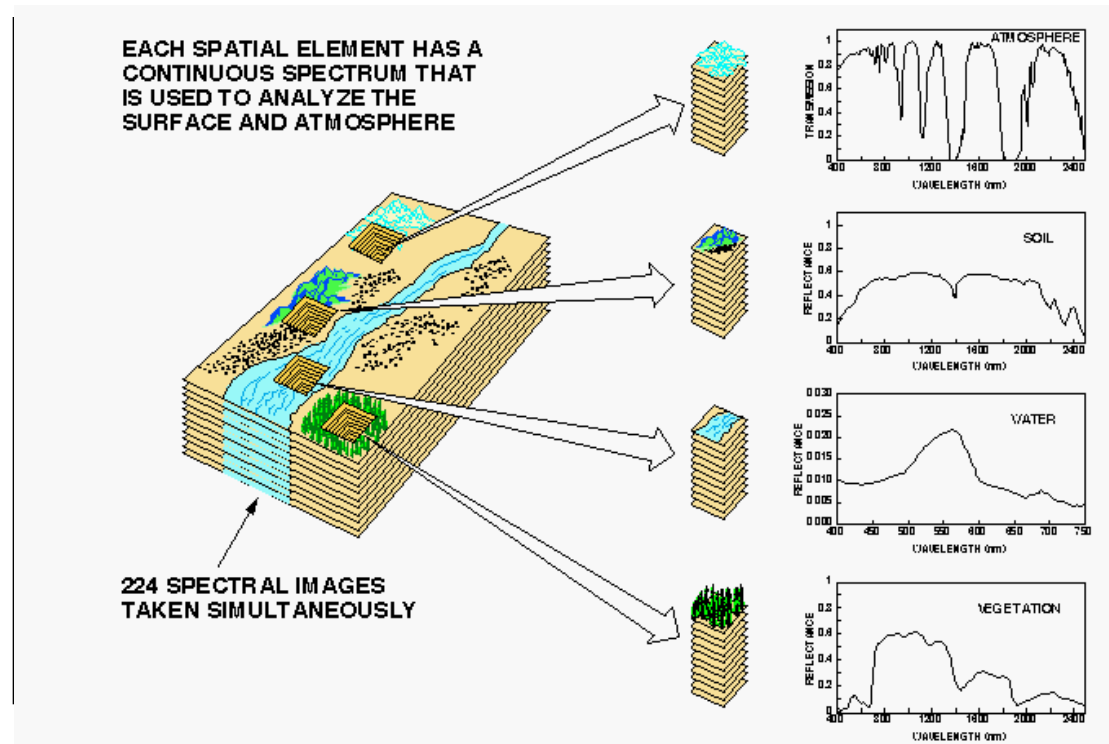


Code Y Science Objectives and Measurement Requirements

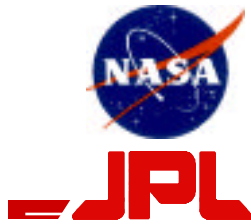
Robert O. Green



Overview of Imaging Spectroscopy

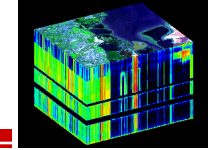


Imaging Spectroscopy enables direct identification of most earth surface materials of interest through their unique spectral signatures

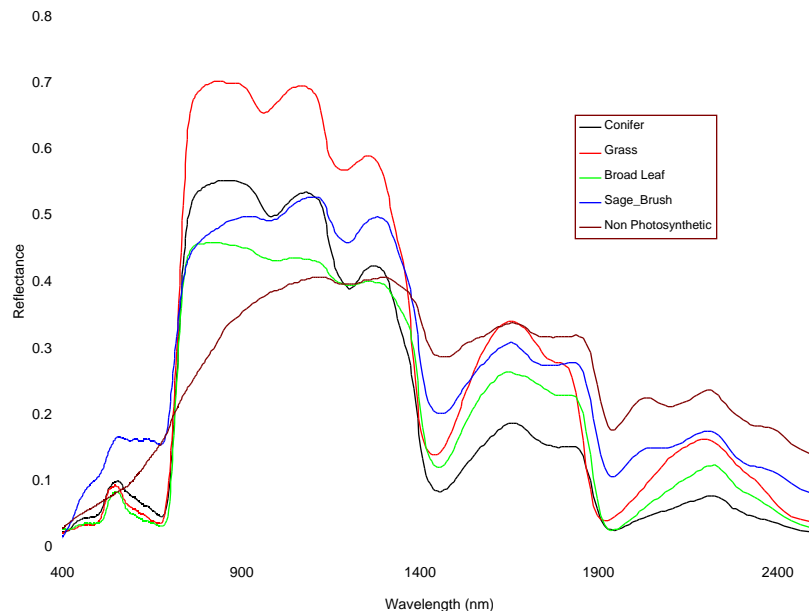


Imaging Spectroscopy Technology Investments

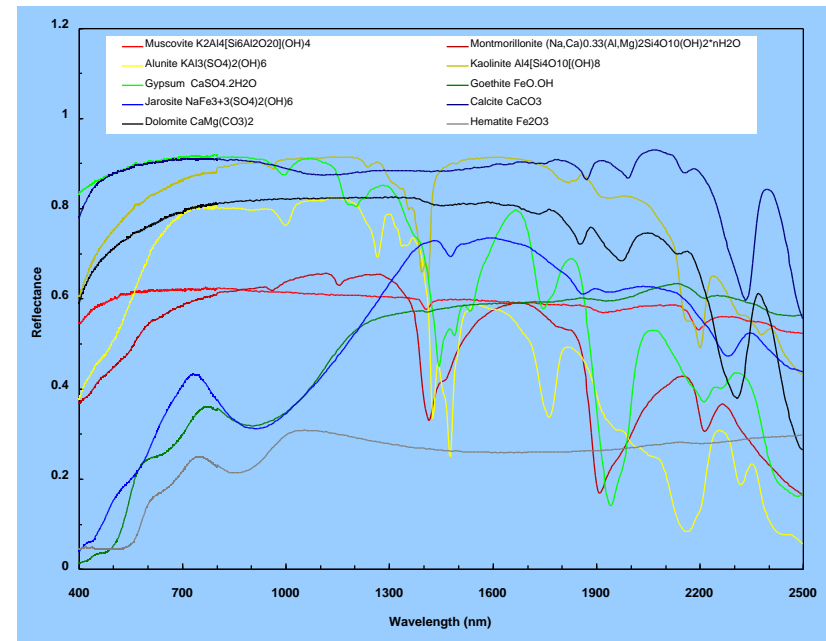
Code Y Science Objectives



Examples of Key Plant and Mineral Spectra



Vegetation Spectra



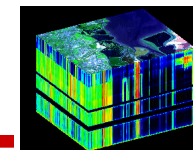
Soil and Rock Mineral Spectra

The detailed structure of these spectra are the key to material identification

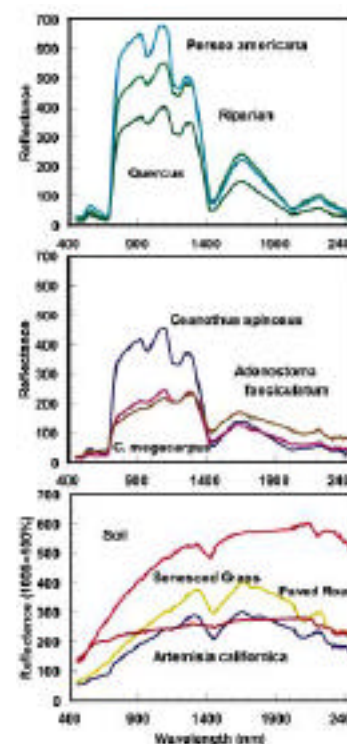
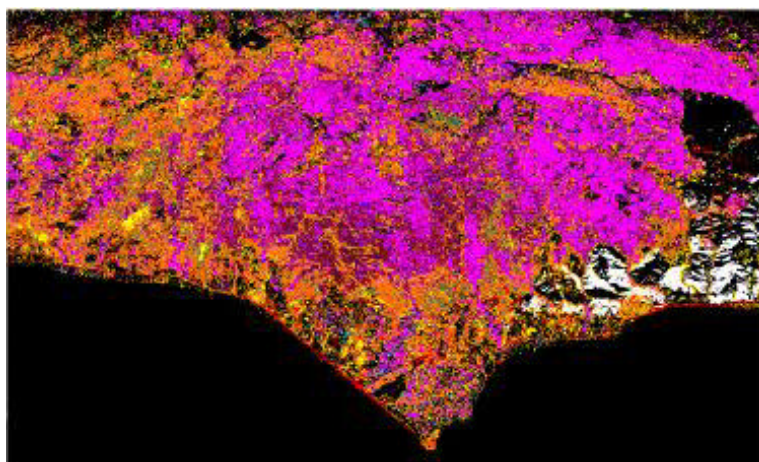


Imaging Spectroscopy Technology Investments

Code Y Science Objectives



Santa Monica Mountains Vegetation Species Map: An Example of the Power of Imaging Spectroscopy



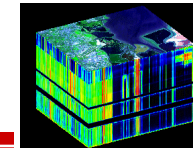
Plant
spectra
derived
from
AVIRIS
data

**AVIRIS data allowed a more accurate mapping
than years of work on the ground**

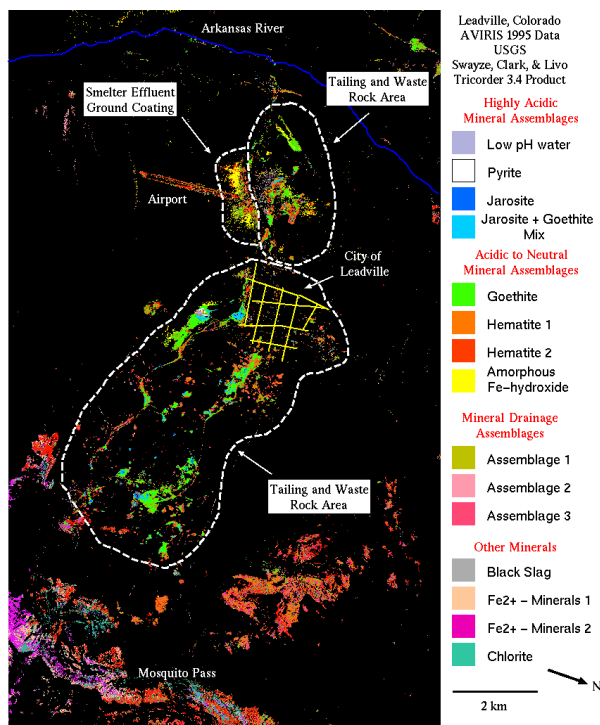


Imaging Spectroscopy Technology Investments

Code Y Science Objectives



Leadville, Colorado Hazardous Waste Map

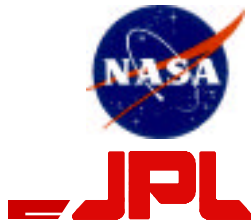


- Leadville was site of unregulated mining since the 1800s
- Acid-generating minerals left at surface at unknown locations
- AVIRIS data used to map these minerals
- *“Use of AVIRIS data has provided an estimated \$2M savings...and shortening of the site investigation process by an estimated 2 1/2 years.”*

Letter to Bill Townsend from the Assistant Regional Administrator, EPA, 2/27/97

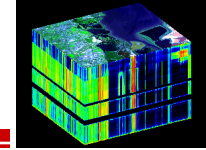
Mineral Map Derived Directly from AVIRIS data

Subtle, diagnostic features in the soil mineral spectra allowed AVIRIS mapping in a fraction of the time, at a fraction of the cost

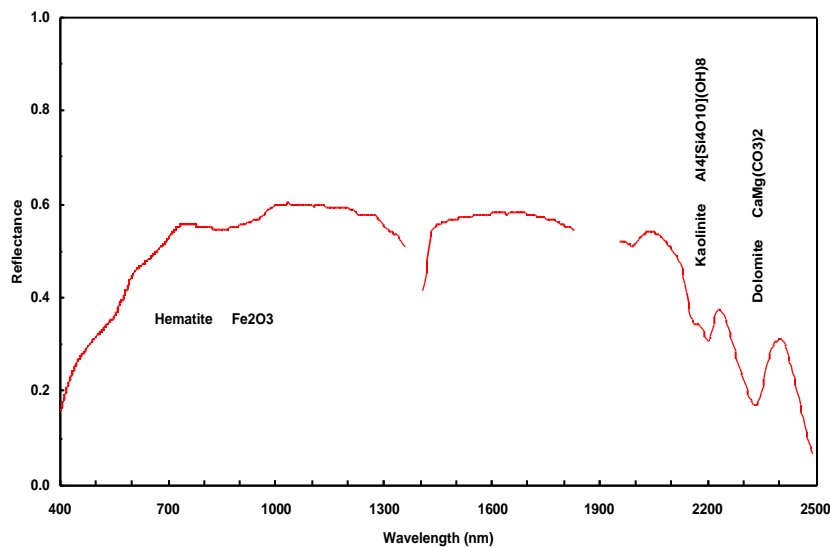


Imaging Spectroscopy Technology Investments

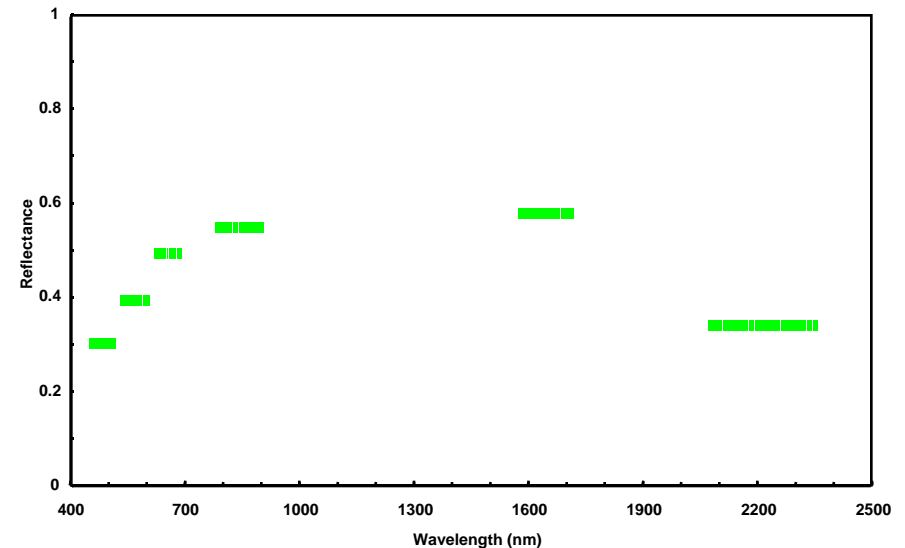
Code Y Science Objectives



Why It Can't Be Done with Multispectral Imaging



AVIRIS Spectra

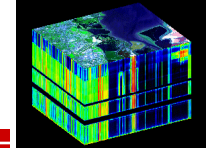


TM - equivalent spectral resolution

The lack of spectral specificity at TM-equivalent spectral resolution results in greatly degraded material mapping capability

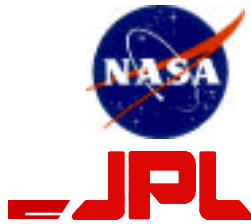


Measurement Requirements



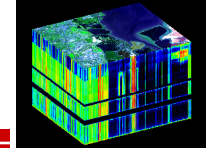
Key Data Parameters That Affect Ability to Map Material of Interest

- **Signal-to-Noise Ratio (SNR)**
 - High performance required to detect key spectral features
- **Spectral purity: No spectral smile!**
 - An artifact of earlier spectrometer design, mixes spectral content across focal plane array
- **Spatial resolution**
 - 30m ground IFOV adequate for most science needs, If SNR and spectral purity are adequate
- **Atmospheric correction**
 - H₂O is ubiquitous, temporally and spatially variable, and masks many key spectral features
- **Calibration**
 - High precision spectral and radiometric calibration required for atmospheric correction and surface material spectral feature extraction

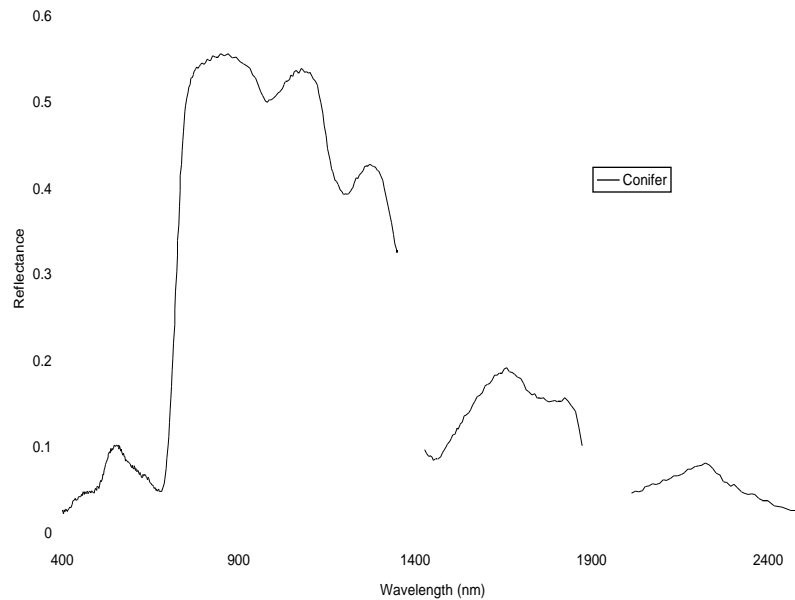


Imaging Spectroscopy Technology Investments

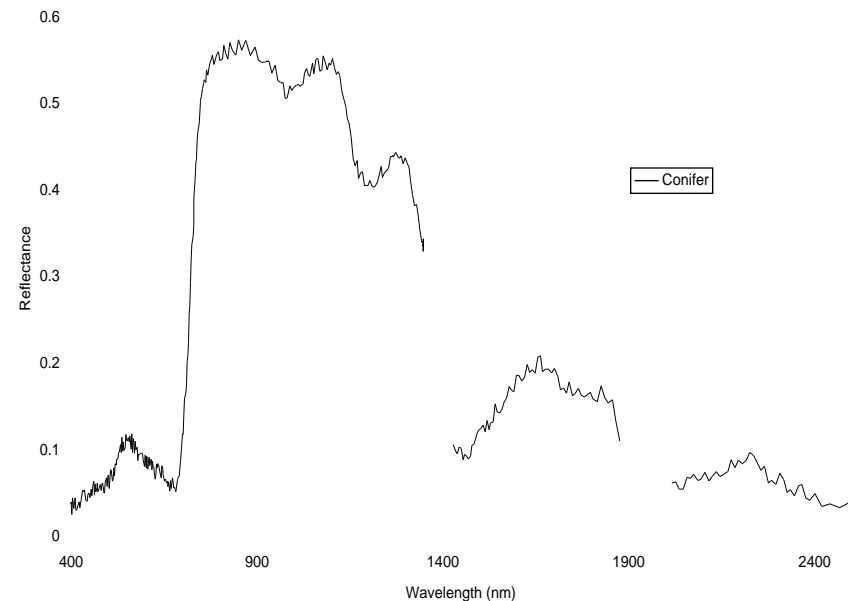
Measurement Requirements



Signal-to-Noise (SNR)

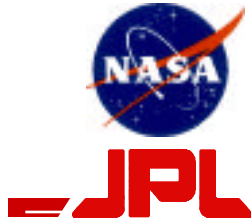


Vegetation spectrum at nominal AVIRIS SNR



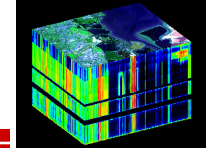
Simulated spectrum at 1/10 AVIRIS SNR

Low SNR masks the key spectral features of interest, which become buried in the noise

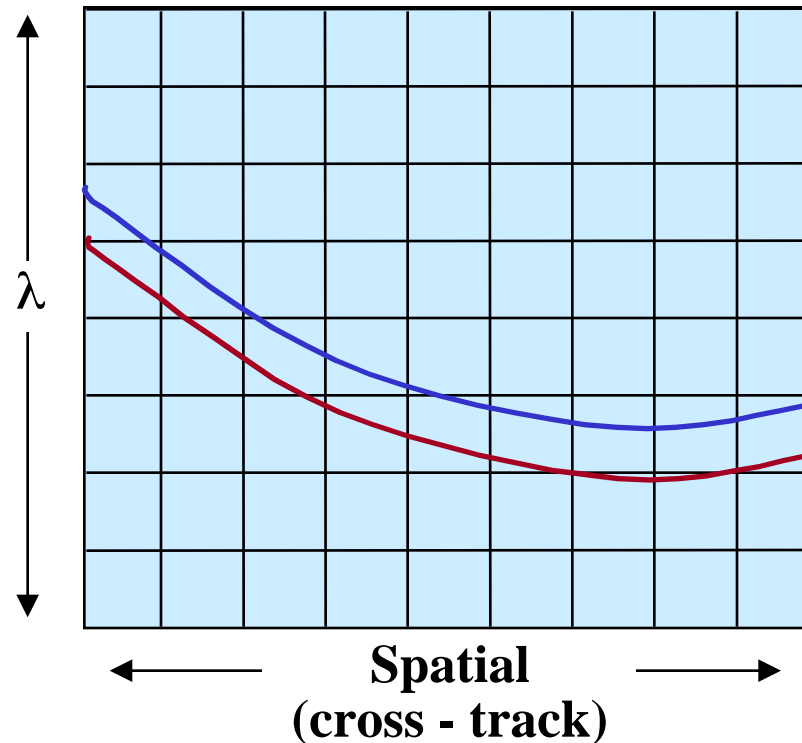


Imaging Spectroscopy Technology Investments

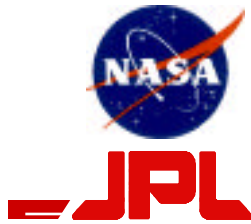
Measurement Requirements



Spectral Purity: Smile

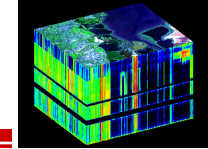


- Spectral “smile” is an artifact of previous grating spectrometer designs using 2-D focal plane arrays
- Effect greatly degrades data quality by mixing spectral and spatial information
- **Maximum allowable spectral smile <1/10 pixel to meet Code Y science objectives**

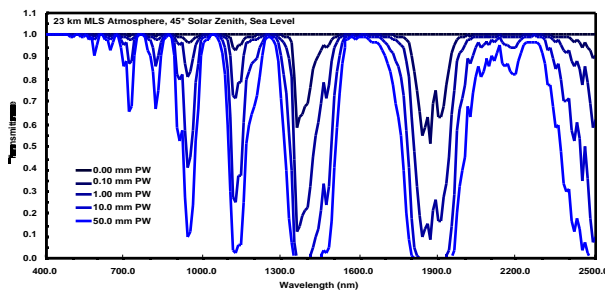


Imaging Spectroscopy Technology Investments

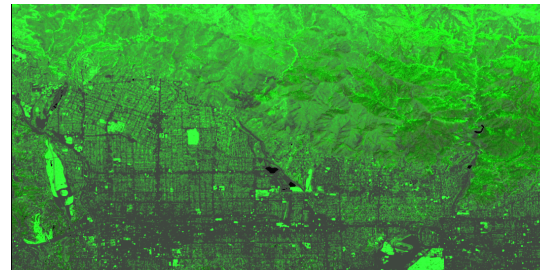
Measurement Requirements



Atmospheric H₂O Vapor Correction



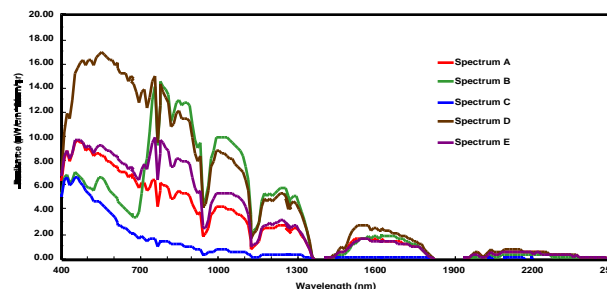
H₂O vapor affects the entire solar reflected spectral region



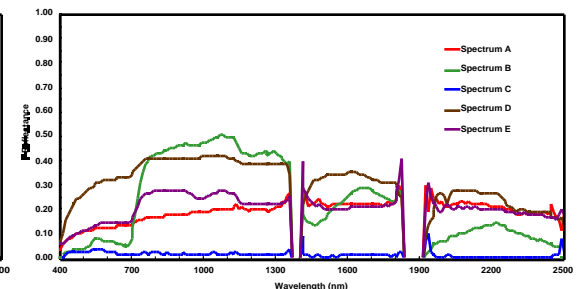
AVIRIS: PASADENA, CA



PASADENA WATER VAPOR

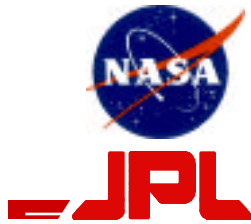


INFLUENCE OF WATER VAPOR



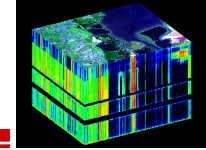
DERIVED REFLECTANCE SPECTRA

Extraction of true surface reflectance spectra requires meticulous correction for H₂O vapor using information from within the imaging spectrometer data themselves

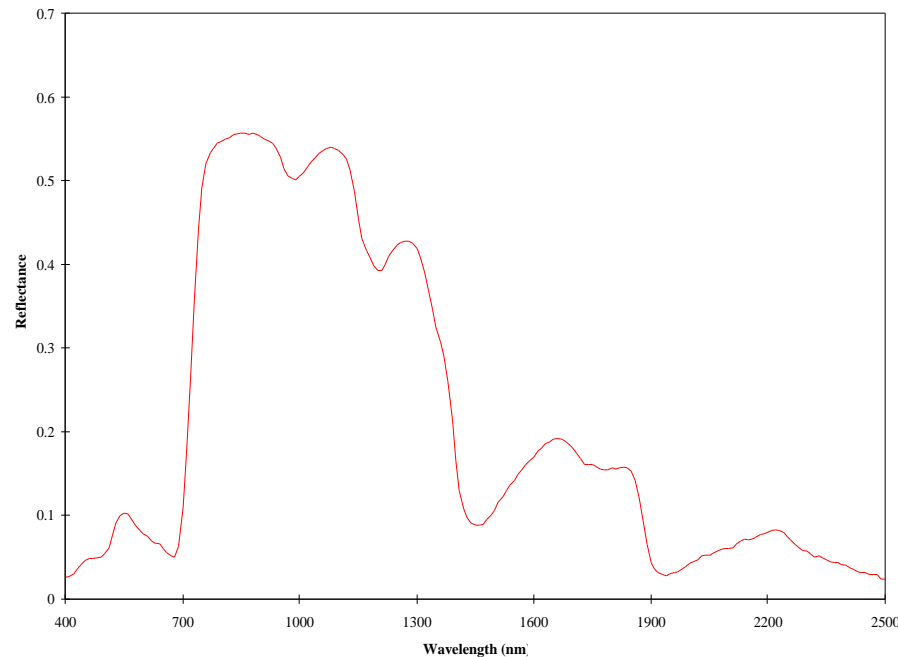


Imaging Spectroscopy Technology Investments

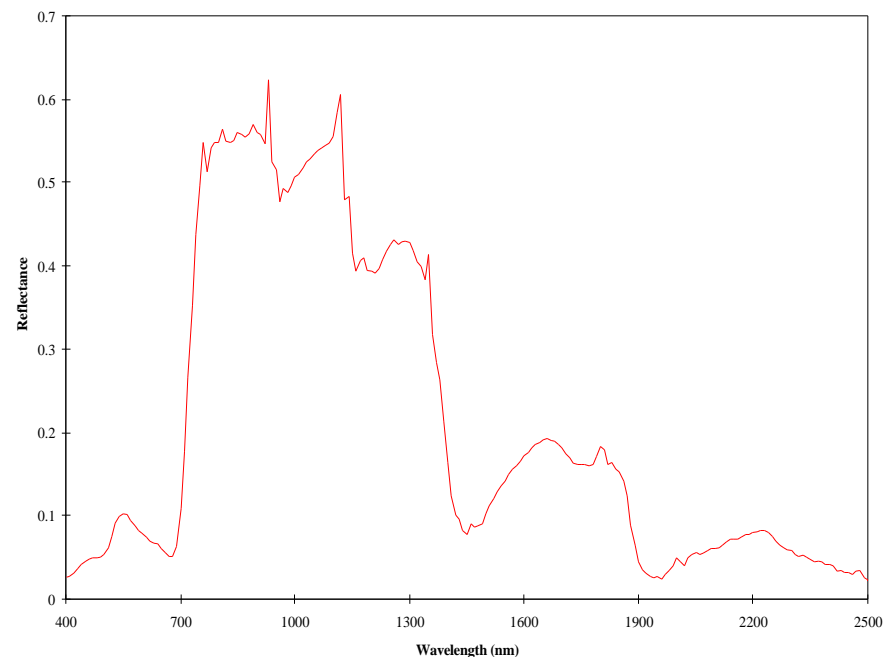
Measurement Requirements



Spectral Calibration



Vegetation Spectrum

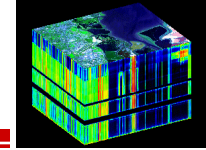


Vegetation Spectrum with 10% spectral calibration error

Poor spectral calibration distorts the apparent positions of key spectral features, introduces unacceptable error in data reduction



Measurement Requirements



In Quantitative Terms:

Signal-to-Noise (SNR)

- VNIR: 1000:1
- SWIR: 500:1

Spectral Coverage

- 0.4-2.5 μ
- 0.010 μ constant bandwidth



Spatial Coverage

- 60 km swath
- 30 m ground pixel size

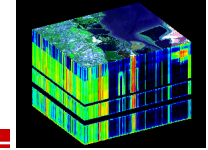
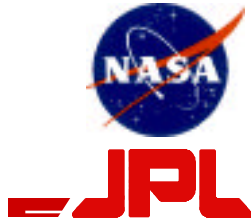
Calibration

- 1% spectral
- 3% radiometric
- 10% spatial

Atmospheric Correction

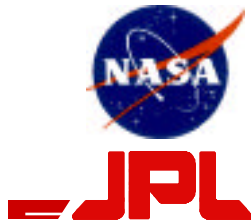
- 1% H₂O

Derived from Almost a Decade of Research with High-quality AVIRIS Data



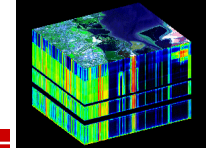
Today's State-of-Practice (SOP) and Examples of a Few Enabling Technologies

David A. Thomas



Imaging Spectroscopy Technology Investments

Today's State-of-Practice



AVIRIS

(airborne)

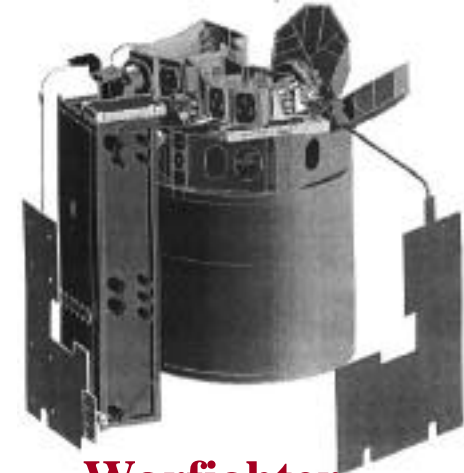
- Operational
- Optimum performance
- High mass (350 kg)



Hyperion

(spaceborne)

- Under development
- Low SNR (~100:1)
- Moderate mass (50kg)



Warfighter

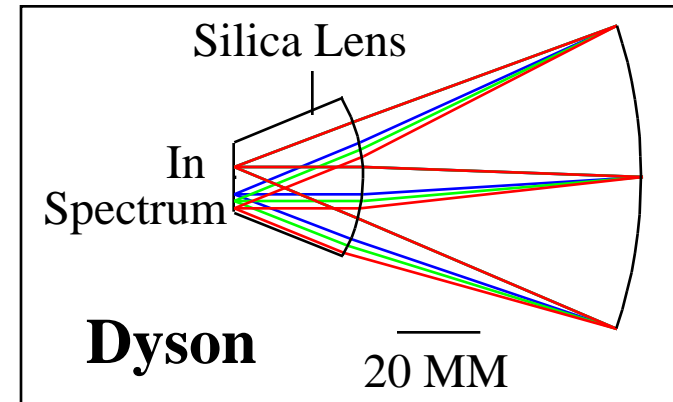
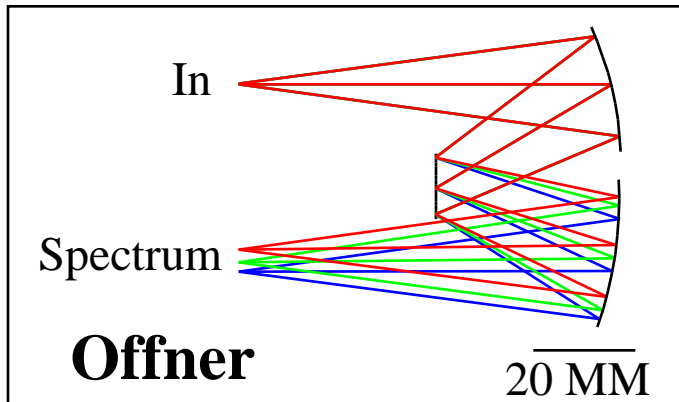
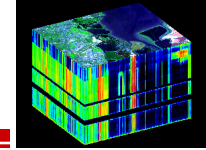
(spaceborne)

- Under development
- Low SNR (~300:1)
- Moderate mass (70kg)

Current spaceborne Imaging Spectrometers will not have the performance needed to meet the Code Y science objectives



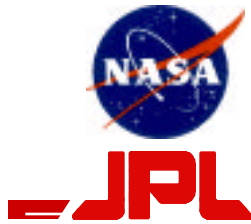
Compact Spectrometer Design Forms



Advantages of both designs:

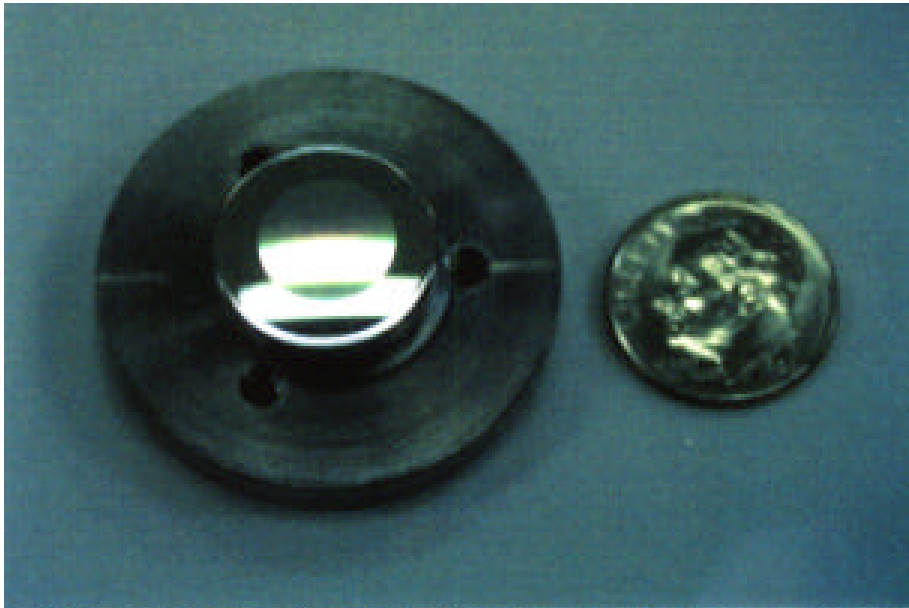
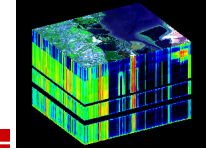
- Smaller than classical forms (3x to 5x)
- Higher performance (wider slits, zero distortion)
- Cheaper to fabricate

Smaller, cheaper, better spectrometers are enabled by new diffraction grating designs



Imaging Spectroscopy Technology Investments

New Diffraction Grating Technology

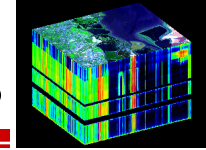
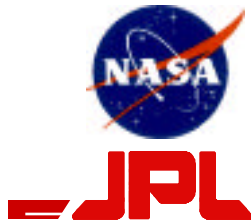


**e-beam grating for New
Millenium EO-1 Mission**

Advantages

- Low scattered light
- High optical throughput
- Excellent image quality

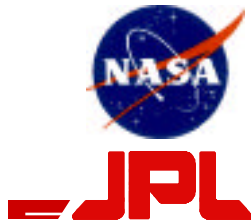
**New fabrication techniques allow new
spectrometer designs to be built inexpensively**



Hybrid Imaging Technology (HIT) CCDs

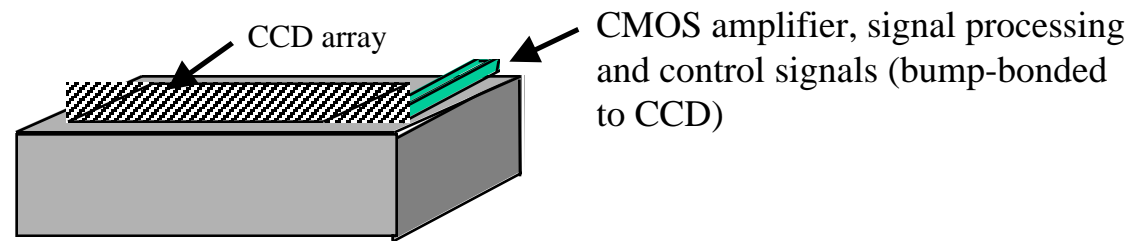
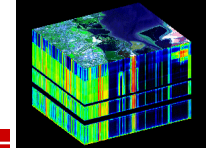
- **Combines the best of two advanced technologies:**
 - Charge-Coupled Devices (CCD) for SOA low-noise performance
 - CMOS VLSI Technology, for low-power, on-chip electronics
 - CMOS amplifier, signal processing package bump-bonded to CCD
 - Same approach can be used with IR detectors
- **Product description:**
 - Photon detection rivaling CCDs
 - Power <25 mW
 - Response linearity >99.6%
 - Radiation tolerance >2 Mrads
 - On-chip ADC 12 bits or greater

On-chip ADC enables reduction in *system* noise of 2-5x compared to conventional technology, yielding much higher *system* SNR

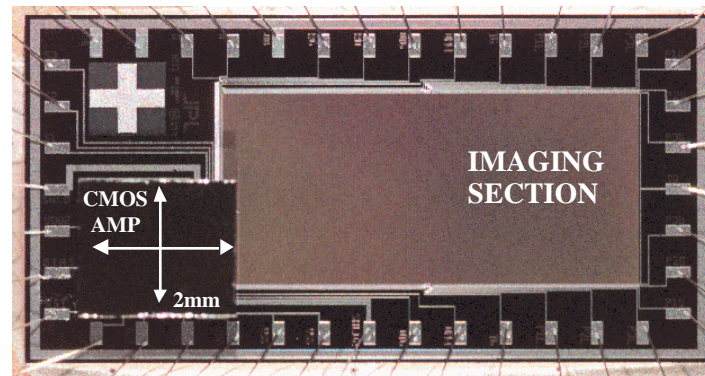


Imaging Spectroscopy Technology Investments

HIT CCDs



HIT CCD System Architecture

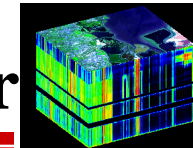


HIT-1 256 x 512 Prototype Sensor (built in 1998)



Imaging Spectroscopy Technology Investments

Images Obtained From HIT-1 Detector



50 e -

- 50 e- in Brightest Portion of Scene
- No Background Subtraction
- No Image Post Processing
- T = - 40 C Operation
- CTE > 0.99999
- 25 kilopixels/sec Data Rate
- 4.8 e- RMS Read Noise Floor
- < 100 Microwatts Power Dissipation



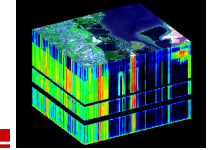
3000 e -

- 3000 e- in Brightest Portion of Scene
- No Background Subtraction
- No Image Post Processing
- T = 0 C Operation
- CTE > 0.99999
- 25 kilopixels/sec Data Rate
- 4.8 e- RMS Read Noise Floor
- < 100 Microwatts Power Dissipation

HIT-1 Establishes New State-of-the-Art for Imaging Technology



Imaging Spectroscopy Technology Investments

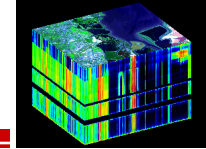


Summary

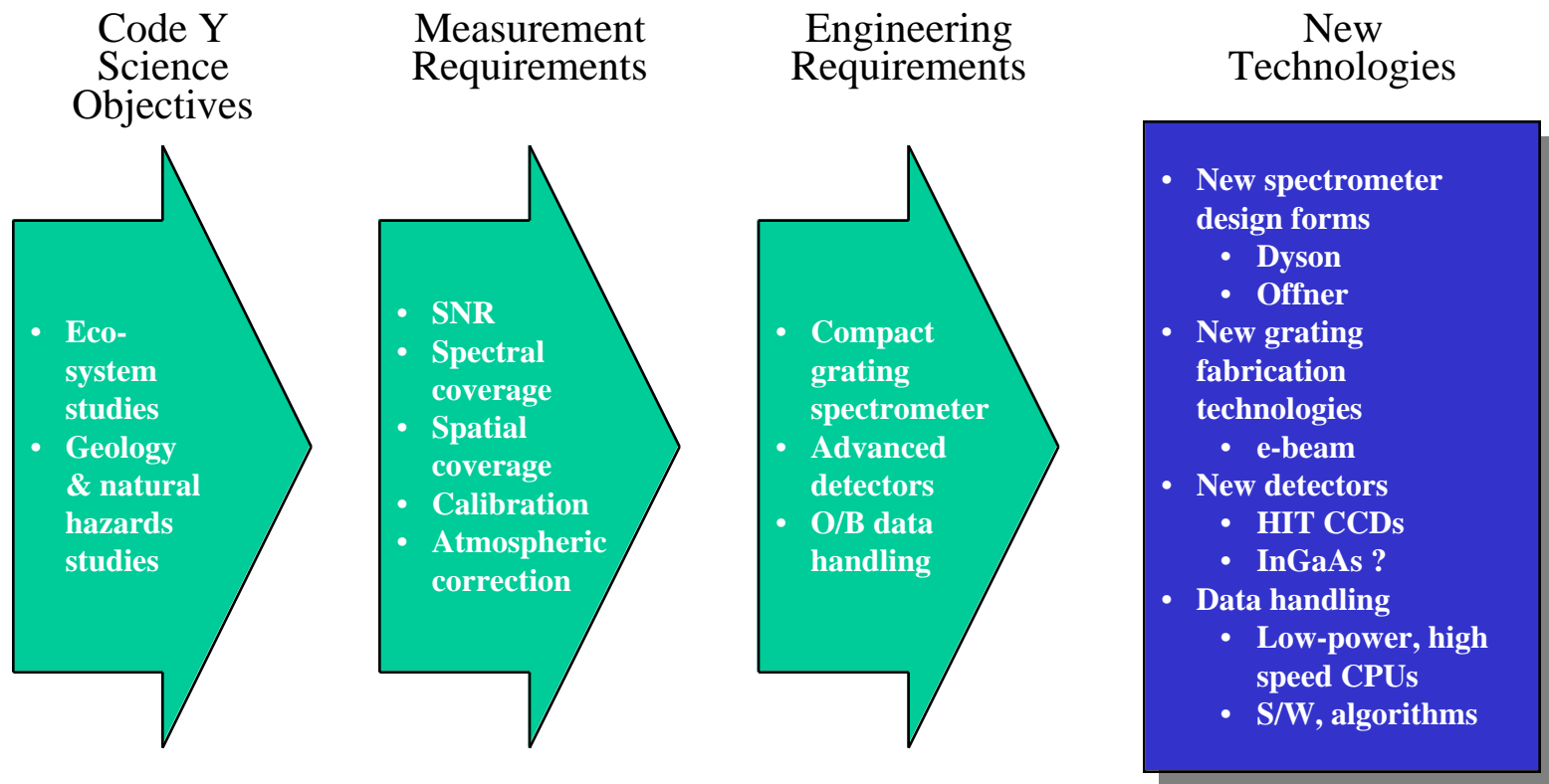


Imaging Spectroscopy Technology Investments

Summary

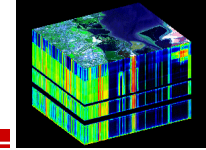


Requirements Flow-Down Leads to Requirements for New Technologies





Conclusion



- **A modest technology investment will enable significant improvement in performance AND reduction in mass/cost of future spaceborne imaging spectrometers**
- **Next steps:**
 - **Develop technology roadmap with industry and NASA partners**
 - **Initialize investments right away in already-identified high-payoff technologies such as optics and detectors**